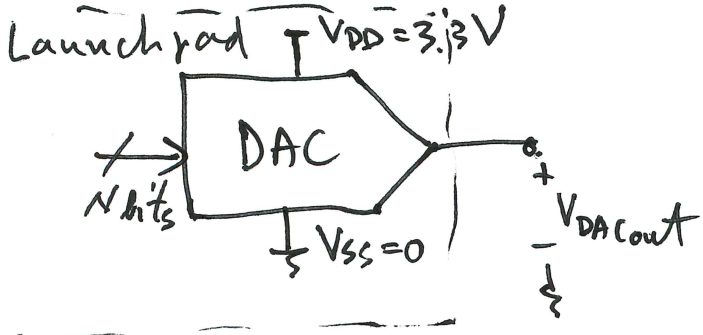
EE16A – Module 2 – Lecture 8

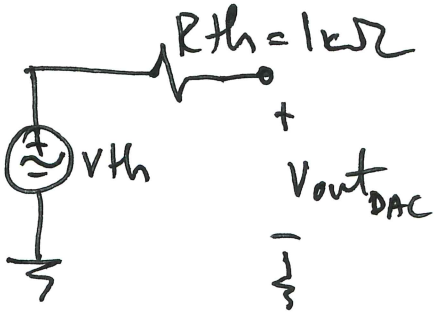
* Audio system (DAC example)
* Intro to negative feedback
* Golden rules
* Op-amp NFB examples

"16A Boombox"



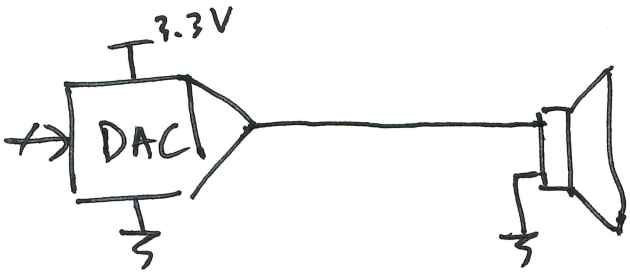
DAC: Digital-to-analog converter (turns digital – binary values into analog voltage)

Model ≡

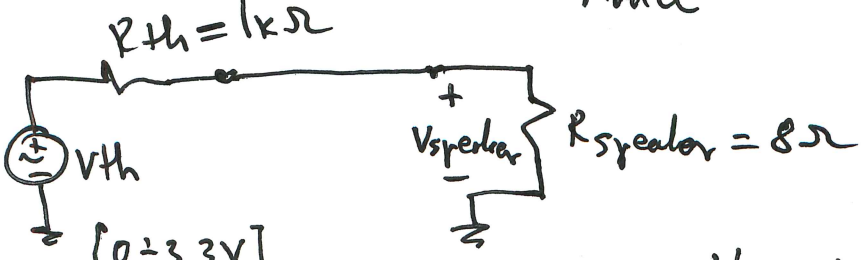


$V_{th} \in [0, 3.3V]$

V_{SS} V_{DD}



// Model



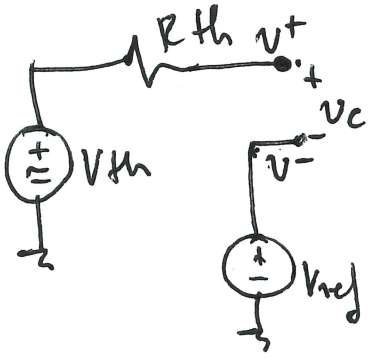
$$V_{speaker} = \frac{R_{speaker}}{R_{speaker} + R_{th}} \cdot V_{th}$$

=

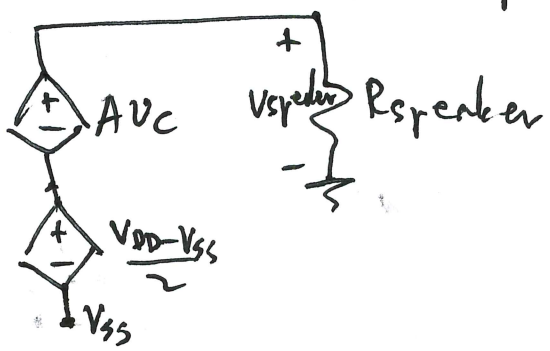
(12)

$$V_{speaker} = \frac{1}{1 + \frac{R_{Th}}{R_{speaker}}} \cdot V_{th} = \frac{1}{1 + \frac{1k\Omega}{8\Omega}} V_{th}$$

Loading effect $\rightarrow$ $= \frac{V_{th}}{126}$



isolate DAC from speaker

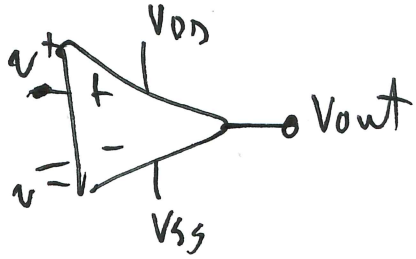


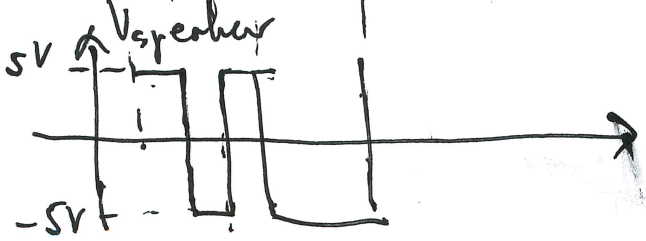
$V_{DD} = V_{+} - V_{SS} = 5V$

$V_{speaker} = A \cdot v_C$

$v_C = V^+ - v^- = V_{th} - V_{ref}$

(Mozart)





(Megadeth)

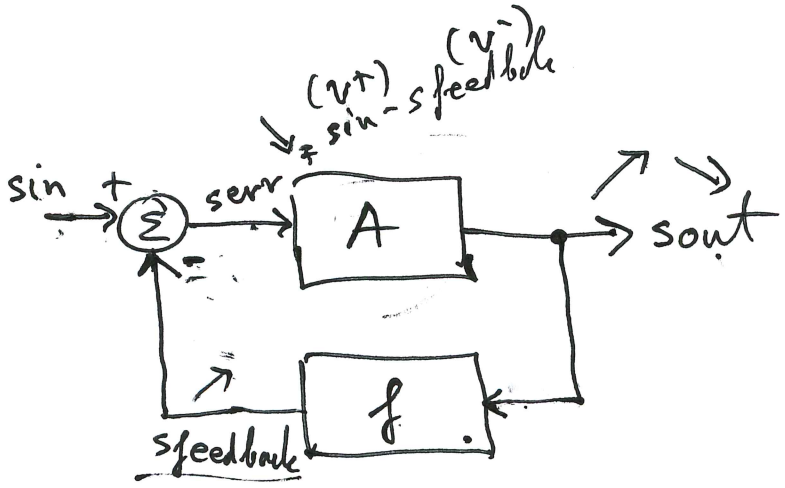
(e3)

Want isolation with a controllable gain ξ (e.g 3×).

Need a way to "tame" the op-amp.

Negative feedback

Concept:



$$\left.\begin{aligned} serr &= sin - sfeedback \\ sout &= A \cdot serr \\ sfeedback &= f \cdot sout \end{aligned}\right\} \quad \begin{aligned} \frac{sout}{A} &= sin - f \cdot sout \\ sout\left(\frac{1}{A} + f\right) &= sin \end{aligned}$$

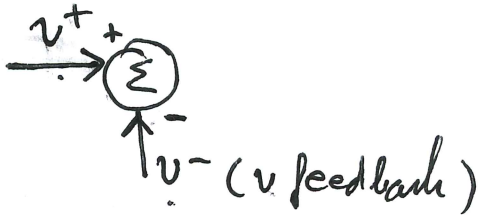
$$\frac{sout}{sin} = \frac{1}{\frac{1}{A} + f} = \frac{A}{1 + Af}$$

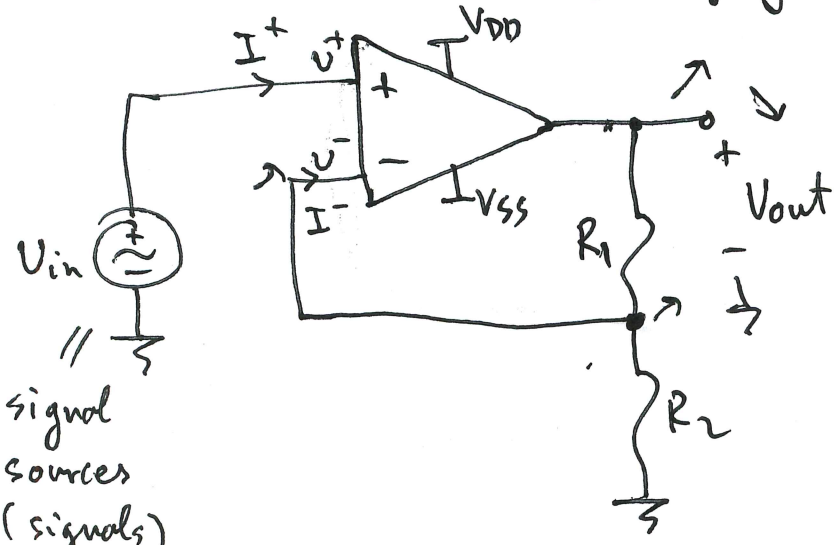
$$\frac{sout}{sin} \underset{A \to \infty}{=\!=} \frac{1}{f}$$

(14)

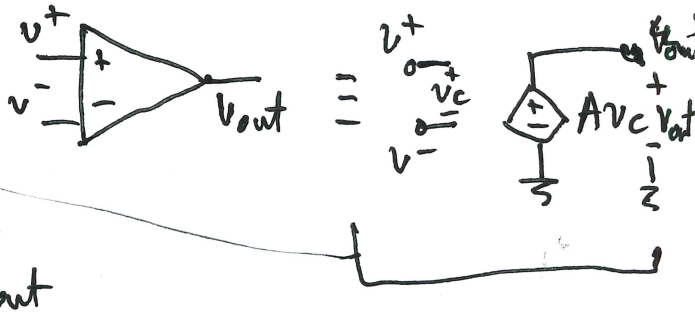
op-amp NFB example:

(non-inverting amplifier)

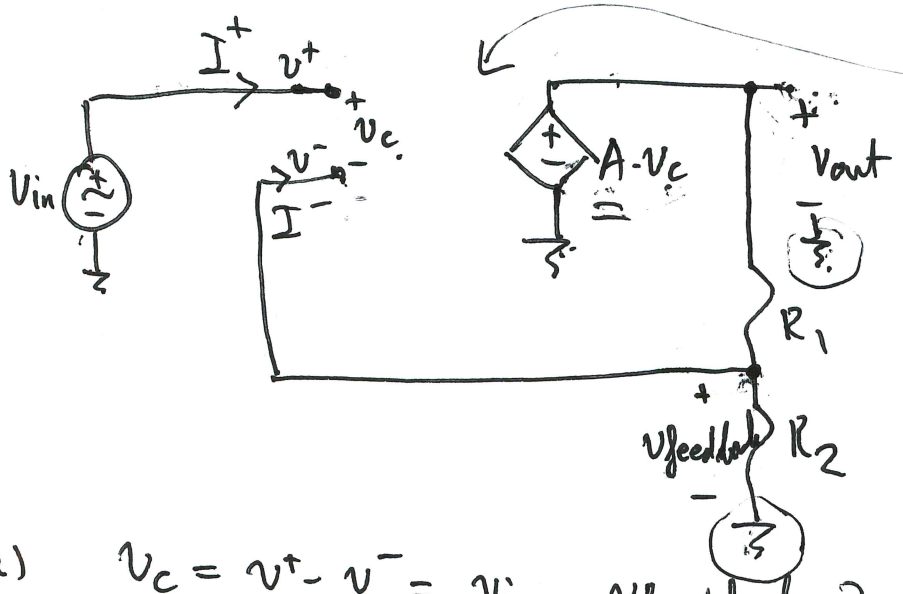


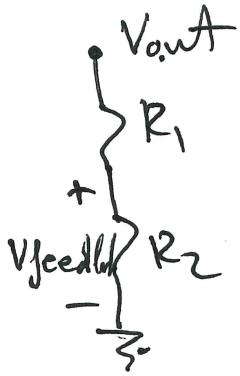


In NFB:



$v_c \equiv$ sew ~~Vout~~ = sout





(1) $v_c = v^+ - v^- = v_{in} - v_{feedback}$

(2) $v_{out} = A \cdot v_c$

(3) feedback $v_{feedback} = \dfrac{R_2}{R_1 + R_2} \cdot v_{out}$

v_{out}

$$v_{out} = A \cdot \left(v_{in} - \frac{R_2}{R_1 + R_2} \cdot v_{out} \right)$$

(15)

$$v_{out} = A \cdot (v_{in} - f \cdot v_{out})$$

$$v_{out} + A f v_{out} = A v_{in}$$

$$v_{out}(1 + Af) = A \cdot v_{in}$$

$$A_v = \frac{v_{out}}{v_{in}} = \frac{A}{1+Af} \underset{A \to \infty}{=} \frac{1}{f} = \boxed{\left(1 + \frac{R_1}{R_2}\right)}$$

$$v_c = \frac{v_{out}}{A} = \frac{1}{A} \cdot \frac{A}{1+Af} \cdot v_{in} = \frac{v_{in}}{1+Af} \underset{A \to \infty}{=} 0$$

$$v_c = v^+ - v^- = 0 \Rightarrow v^+ = v^-$$

when NFB and $A \to \infty$

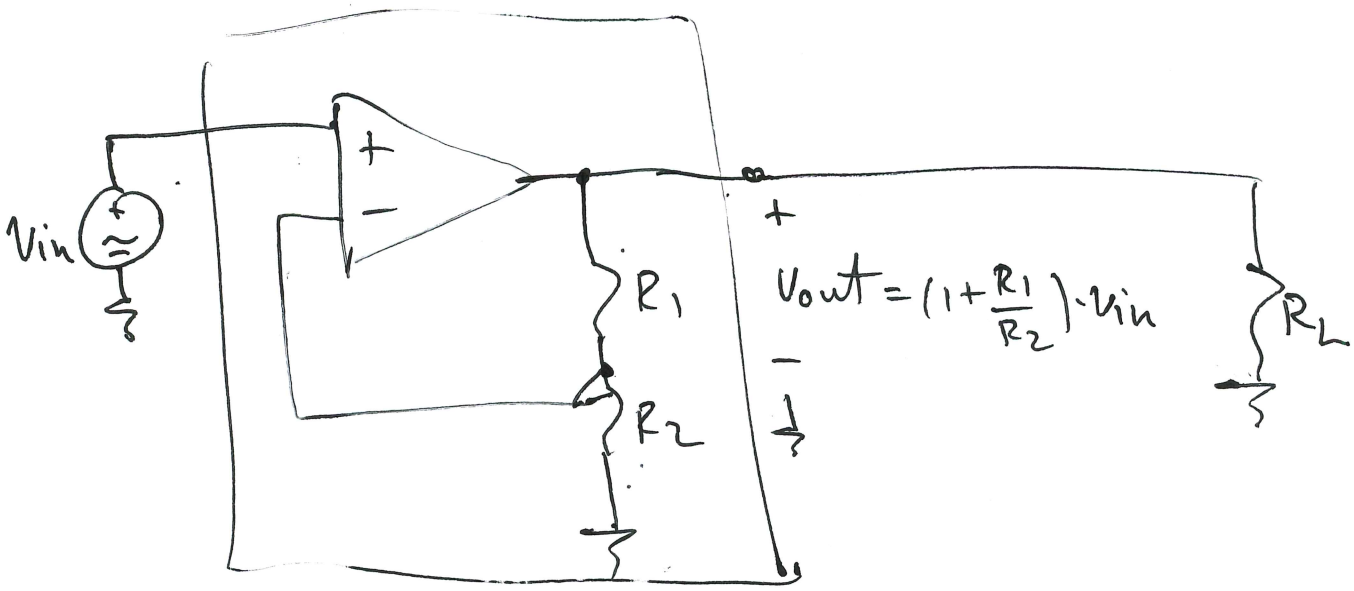
Golden rules

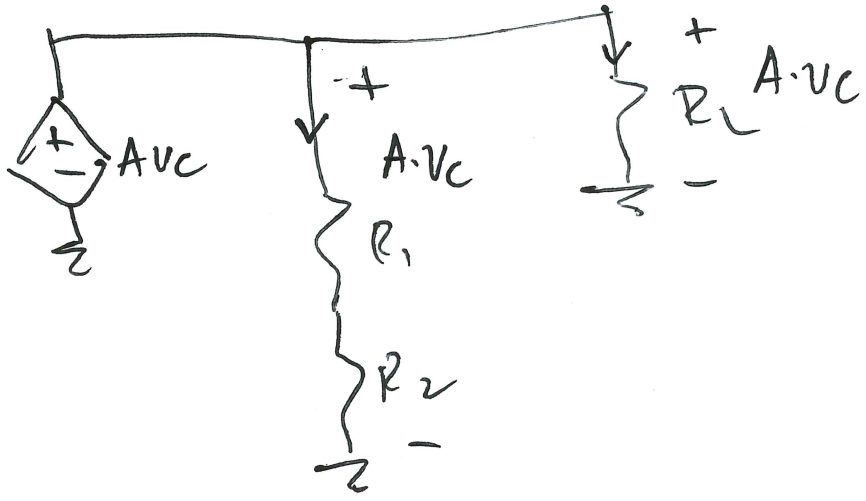
(1) $I^+ = I^- = 0$ (always true)

(2) $v^+ = v^-$ when NFB (and $A \to \infty$)

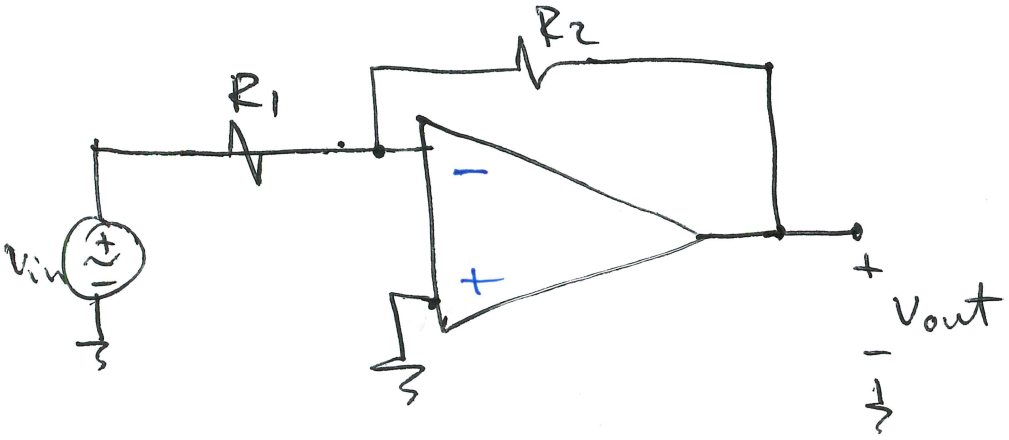
$$A_v = 3 = \frac{v_{out}}{v_{in}} \Rightarrow R_1 = 2R_2$$

$$A_v = \left(1 + \frac{R_1}{R_2}\right) = 3$$


Vin
+
−
R1
R2
+
Vout = (1 + R1/R2) · Vin
−
RL

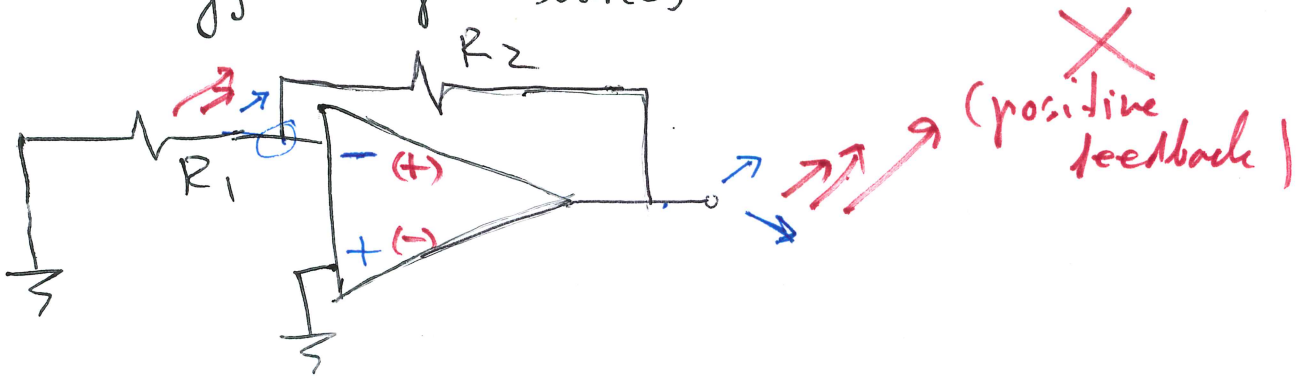

+
−
AVc
+
A·Vc
R1
R2
−
+
RL
A·Vc
−

(4) Another example:



Determining the polarity for NFB:

(1) Turn-off indep. sources



(2) Apply disturbance to the output (and follow the feedback)